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Ice Jam at the Rio Blanco Diversion Weir on the White River in Colorado

A Case Study of In-Stream Structures and Ice

Andrew M. Tuthill

February 2008

COVER: Breached rock weir on Colorado's White River, about 18 miles south of Meeker.

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Andrew M. Tuthill

US Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

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Abstract: In-stream structures constructed of natural materials are increasingly popular on US rivers. Examples include rock weirs, which provide an aesthetic means of pooling and diverting flow for irrigation and lake filling. Though considerable progress has been made in the design and construction of these soft engineering structures, most applications to date have been on rivers that are unaffected by ice. Recent experience shows that the presence of ice can have unexpected and possibly negative results. This report presents a case study of a rock diversion weir that caused a freezeup ice jam, channel shifting, and upstream flooding. The event is described and its causes analyzed. Preliminary guidance is offered on designing against similar ice problems when locating these new types of structures on rivers with ice.

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Preface

This technical report was prepared by Andrew M. Tuthill, Research Hydraulic Engineer, Ice Engineering Research Group, RS/GIS and Water Resources Branch, US Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

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This report was prepared under the general supervision of Timothy Pangburn, PE, Chief, RS/GIS and Water Resources Branch; Dr. Justin B. Berman, Chief, Research and Engineering Division, CRREL; Dr. Lance D. Hansen, Deputy Director, CRREL; and Dr. Robert E. Davis, Director, CRREL.

At the time this work was performed, Colonel Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

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Multiply	By	To obtain
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feet	0.3048	meters
inches	0.0254	meters
miles	1,609.347	meters
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters

1 Introduction

In-stream structures constructed of natural materials are increasingly popular on US rivers. Examples include cross vanes, U-drops, and rock weirs, designed to direct flow toward the channel center, create pools and riffles, and improve flow diversity. Benefits include bank stabilization, grade control, and improved fish habitat. In addition to their uses in river restoration, rock weirs provide an aesthetic means of pooling and diverting flow for purposes of irrigation and lake filling. Over the last several decades, considerable progress has been made in the design and construction of these soft engineering structures. Most applications to date, however, have been on rivers that are unaffected by ice. Recent experience shows that the presence of ice can have unexpected and possibly negative results. The problems result in part since little guidance exists for the design of in-stream structures on ice-affected rivers. This report presents a case study of a rock diversion weir that caused a freezeup ice jam, channel shifting, and upstream flooding. The event is described and its causes are analyzed, and preliminary guidance is offered on designing against similar ice problems.

2 Rio Blanco Weir Ice Event

In December 2005, a freezeup ice jam formed upstream of a newly heightened diversion weir located on the White River, about 18 miles downstream of the town of Meeker, Colorado. Figure 1 shows a map of the project area. The purpose of this 7-ft-high porous rock structure is to divert flow for the White River into Rio Blanco Lake, a wildlife area managed by Colorado Division of Wildlife (CDOW).

At the request of the US Army Corps of Engineers' (USACE) Colorado Regulatory Field office located in Grand Junction, Colorado, a CRREL Ice Engineer visited the site on 16–20 January 2006. The effort was funded by the Wetlands Regulatory Assistance Program (WRAP).

Objectives were to learn about the current ice jam situation and determine what role heightening of the weir may have played in initiating the ice jam.

Other goals were to develop both short- and long-term solutions to the ice jam problem. It is hoped that this experience will improve our understanding of the effect of in-stream structures on river ice processes, and ultimately aid in development of design guidelines with respect to ice, a research effort that is under way at CRREL. Currently, very limited guidance exists for this type of in-stream structure on ice-affected rivers.

Background

The White River below Meeker is a step-riffle system with a relatively uniform bed slope of about 0.0037 that meanders through floodplain fields and meadows about ¼ to ½ mile in width. Figure 2 shows the approximate river bed profile, taken from USGS 1:24,000, 20-ft-contour quad maps. Channel width ranges from 100 to 150 ft, and channel sinuosity is about 1.35. The bed material is predominantly gravel to cobble size, with an average diameter of about 1.5 inches. Average winter base flow at the USGS gage below Meeker is about 350 cfs and peak annual flows resulting from snowmelt runoff in late May to early June average about 2000 cfs. Figure 3 shows the discharge levels for the winter of 2005–2006 to be relatively close to long-term averages. The drainage area at this gage is 1024 miles^2. The spring rise on the White River is sufficiently gradual that the ice cover generally melts in place rather than breaking up dynamically. For this reason, breakup ice jams are not an important factor on the White River.

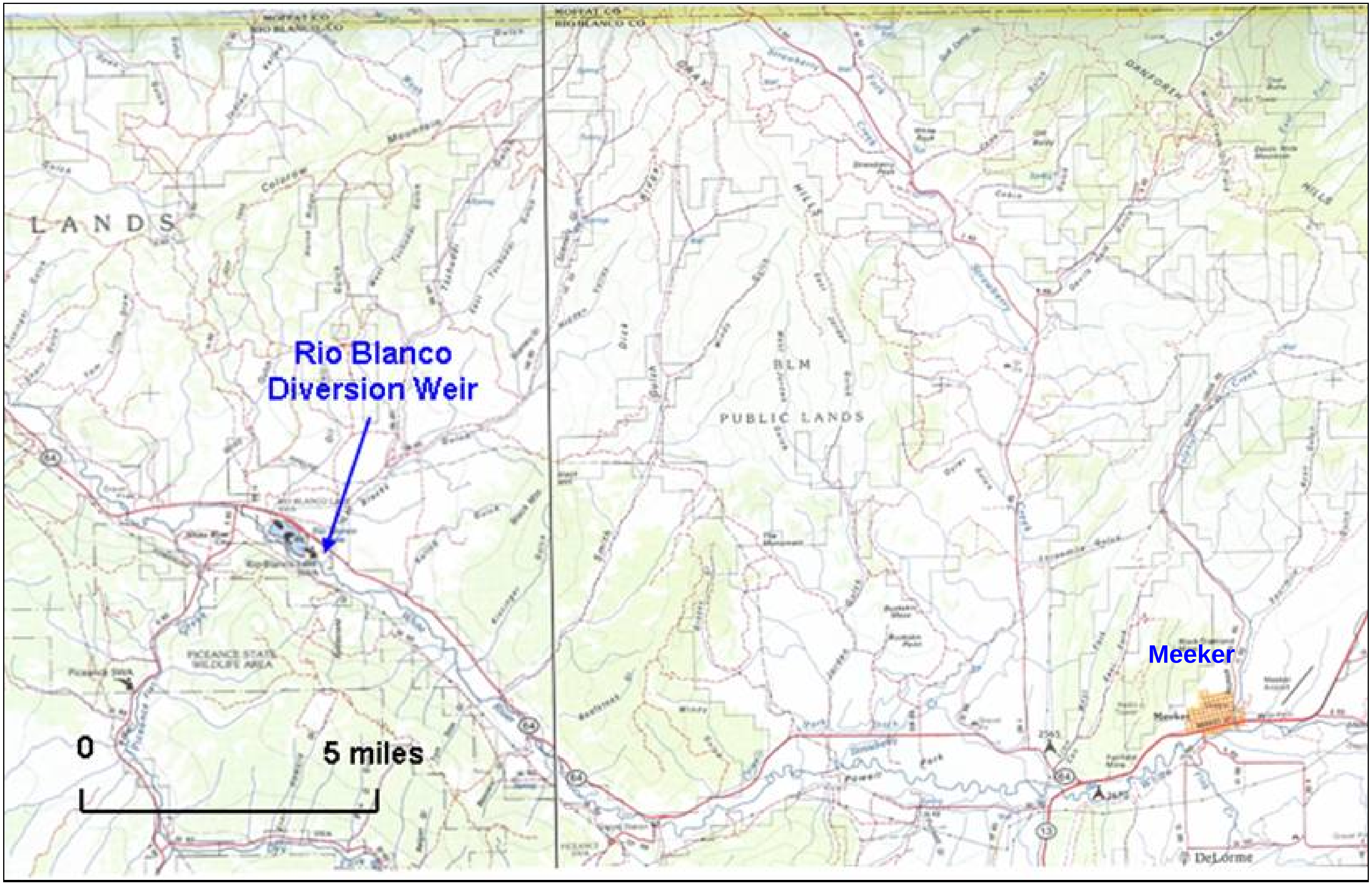

Figure 1. Project location.

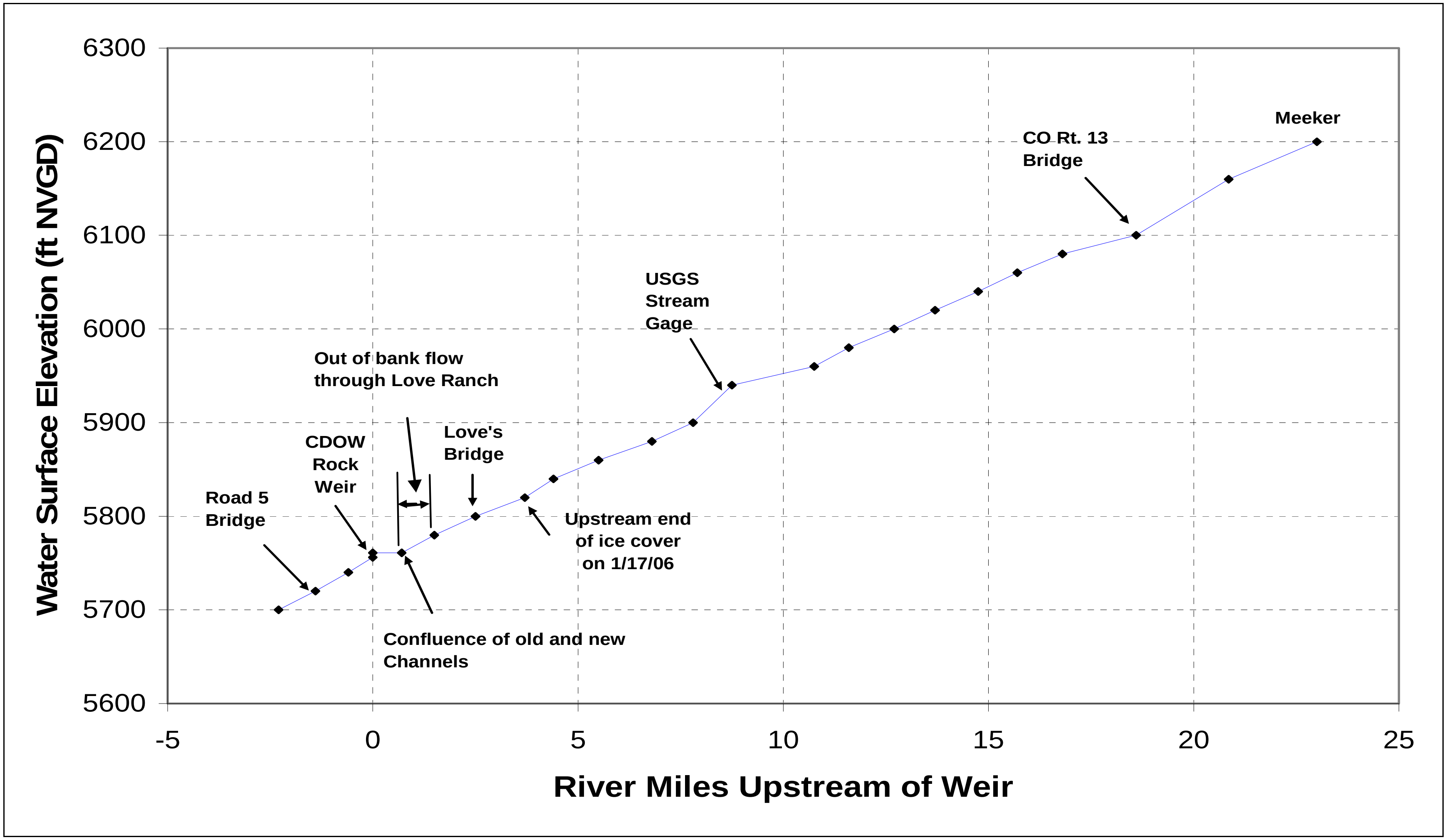

Figure 2. Approximate bed profile of White River below Meeker, Colorado.

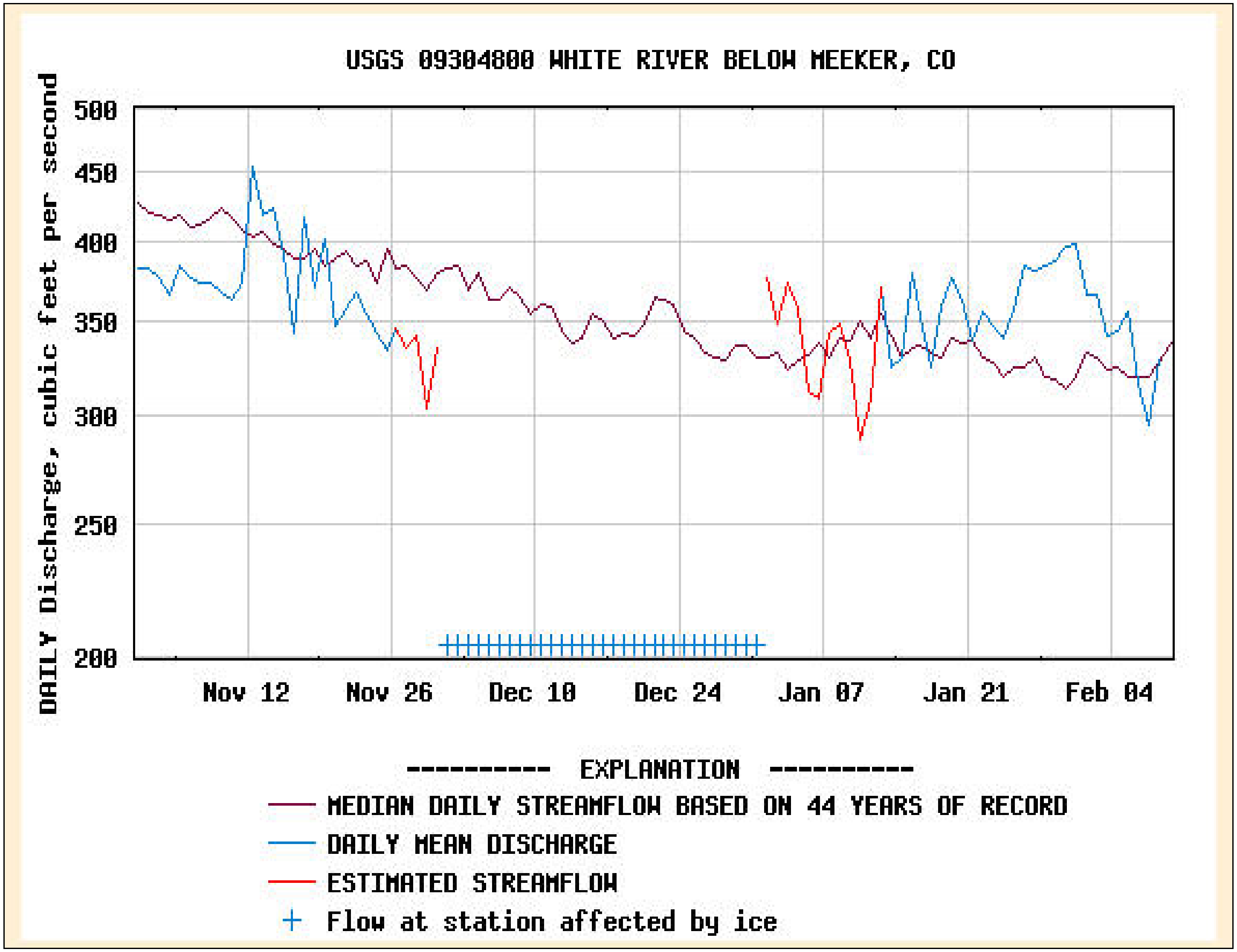

Figure 3. White River discharge below Meeker, Colorado. Note that an ice cover existed at the gage location (eight river miles upstream of the CDOW weir) from 29 November to 30 December 2005.

The White River Valley bottomland below Meeker hosts irrigated crops and cattle grazing. Owing to its relatively steep gradient and high elevation, the White River generates and transports much frazil ice. During periods of extreme cold, freezeup ice covers and ice jams form on the White River, and, during a particularly severe winter in the late 1970s, an ice cover is said to have progressed from Rangely, Colorado, upstream beyond Meeker, causing flooding and hardship in the town of Meeker[1]. The CRREL Ice Jam Database (IJDB) reports a 31 January 1979 freezeup ice jam as "the worst in memory," with flooding of a trailer park in Meeker. The event caused an estimated $50K in damages and a record peak stage of 12 ft at the USGS gage located just above Meeker. Attempts to break the jam using dynamite were reportedly unsuccessful, as was application of coal dust by airplane. The IJDB reports similar, but less severe, jams in Meeker for the years of 2002, 1989, 1984, 1982, 1973, 1962, and 1951.

It is interesting to note that no ice jam flooding was reported in the town of Meeker this December at the time of the downstream ice jam event. Based on discussions with locals, ice jams in this part of the river are a new phenomenon.

Ice Jam Formation

The freezeup ice jam formed during an early December cold snap at the rock weir structure that diverts water to Rio Blanco Lake. Figure 4 shows the jam at the structure on 15 December 2005.

In the fall of 2005, the weir had been redesigned and heightened about 4 ft to better divert flow into the Rio Blanco Lake. Figure 5 shows before and after cross sections of the weirs. The new weir had a level crest with a lower 25-ft-wide spillway section, whereas the previous weir was more U-shaped, conforming to the natural riverbed cross section. Under low flow, open water conditions, the design change resulted in a water level rise at the weir of about 2 ft.

Within a week of its formation, the jam had progressed about five miles upstream of the weir, forcing nearly all flow from the main river channel across the alfalfa fields of a working cattle ranch owned by Sam Love of Meeker. At that time, an ice cover had formed on much of the White River upstream as far as Meeker. Figures 6–8 are aerial photos of the jam and

[1] Discussion with Lani Coulter of Coulter Aviation

flooded fields owned by Love, and Figure 9 is a general site map. The floodwaters and frazil ice deposits isolated the ranchers' winter hay supply and calving yard. About one mile upstream, the ice jam threatened a steel bridge also owned by Love. Also, thousands of feet of cattle fencing and numerous irrigation structures were inundated and frozen in, the degree of damage unknown until spring.

Figure 4. Ice jam at CDOW weir on 15 December 2005.

Below the Love property, the out-of-bank flow entered a wetland, which drained into a secondary channel that then conveyed nearly all the flow (Fig. 7). Because almost no flow passed beneath the grounded jam in the main channel, very little melting had taken place by mid-January, even though the air temperatures had been moderate (Fig. 10 and 11). Records from the USGS gage below Meeker indicate that an ice cover existed at the gage site, eight miles upstream of the CDOW weir, from 29 November to 30 December 2005 (Fig. 3). Whether this ice cover in the vicinity of the gage retained or passed frazil ice from upstream is uncertain. By mid-

January, however, most of the ice cover upstream of the jam had melted. The USGS gage located just upstream of Meeker had had no reports of ice that winter, indicating open water upstream conditions existed, ideal for frazil production during periods of sub-freezing air temperatures.

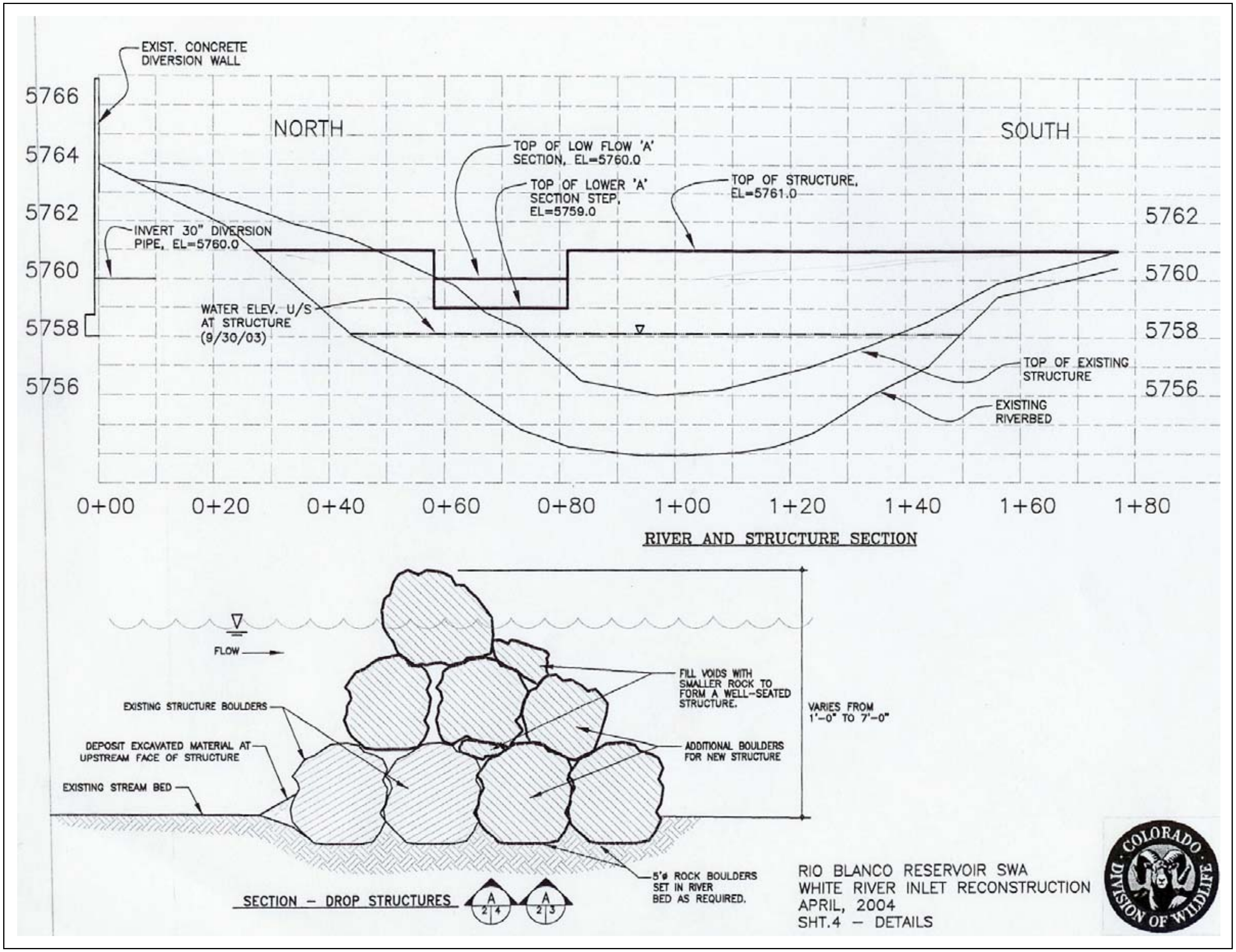

Figure 5. Section views of CDOW rock weir.

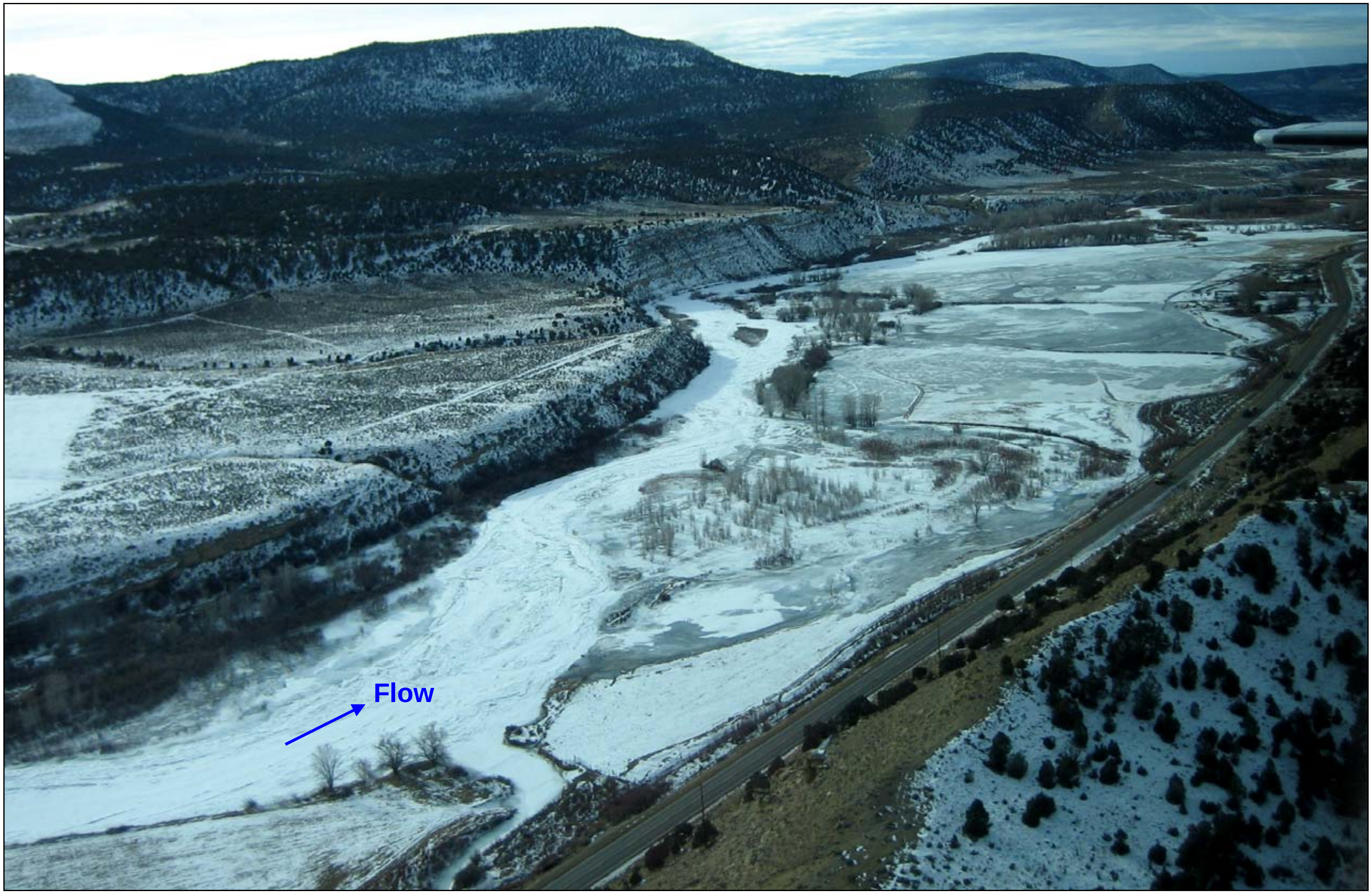

Figure 6. Looking downstream on 17 January 2006, showing ice jam filling main channel on left, forcing flow across Love property on right.

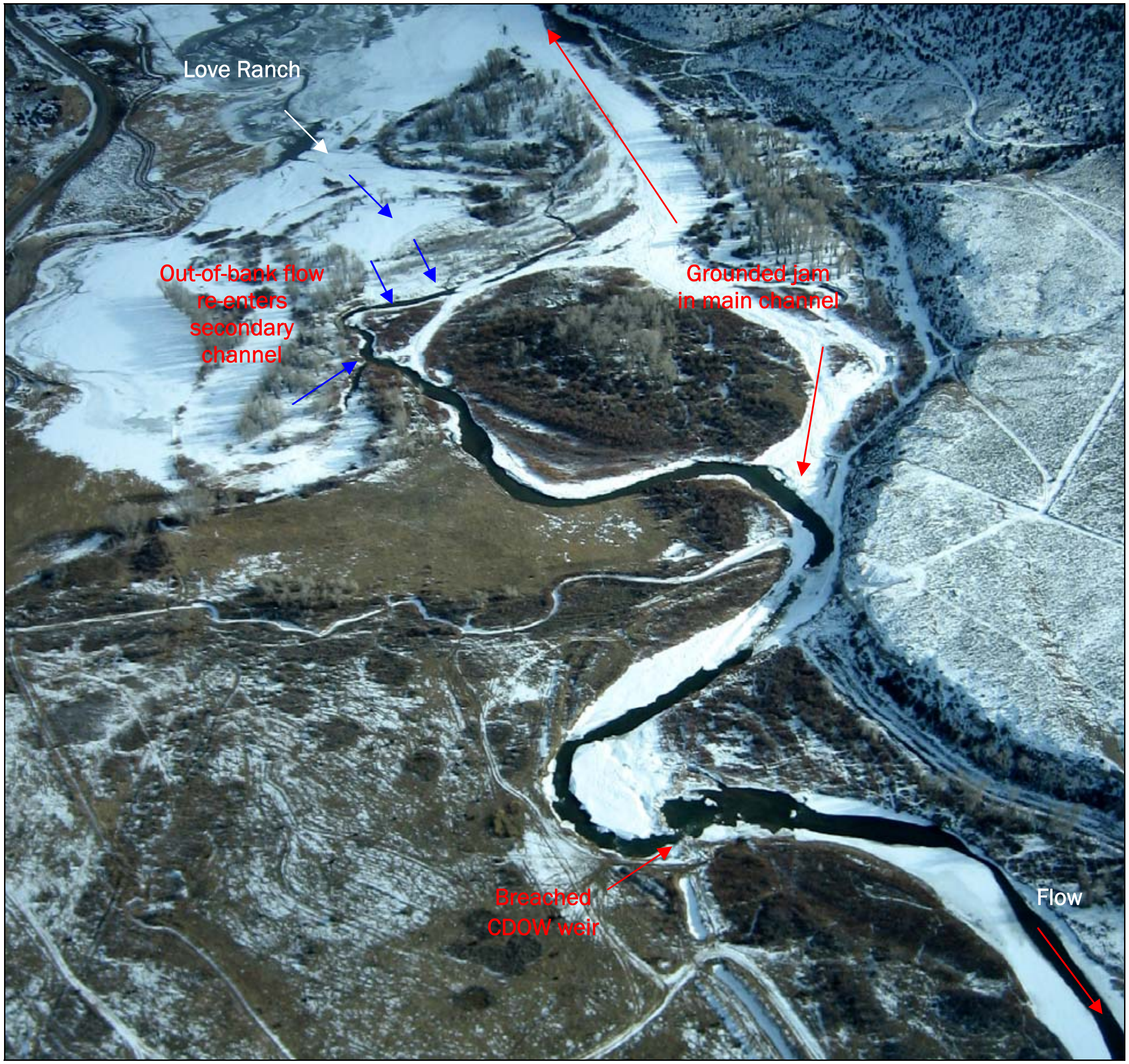

Figure 7. White River downstream of Love property, 17 January 2006.

Figure 8. Flooded fields at Love property on 17 January 2006. Ice jam fills main channel in background.

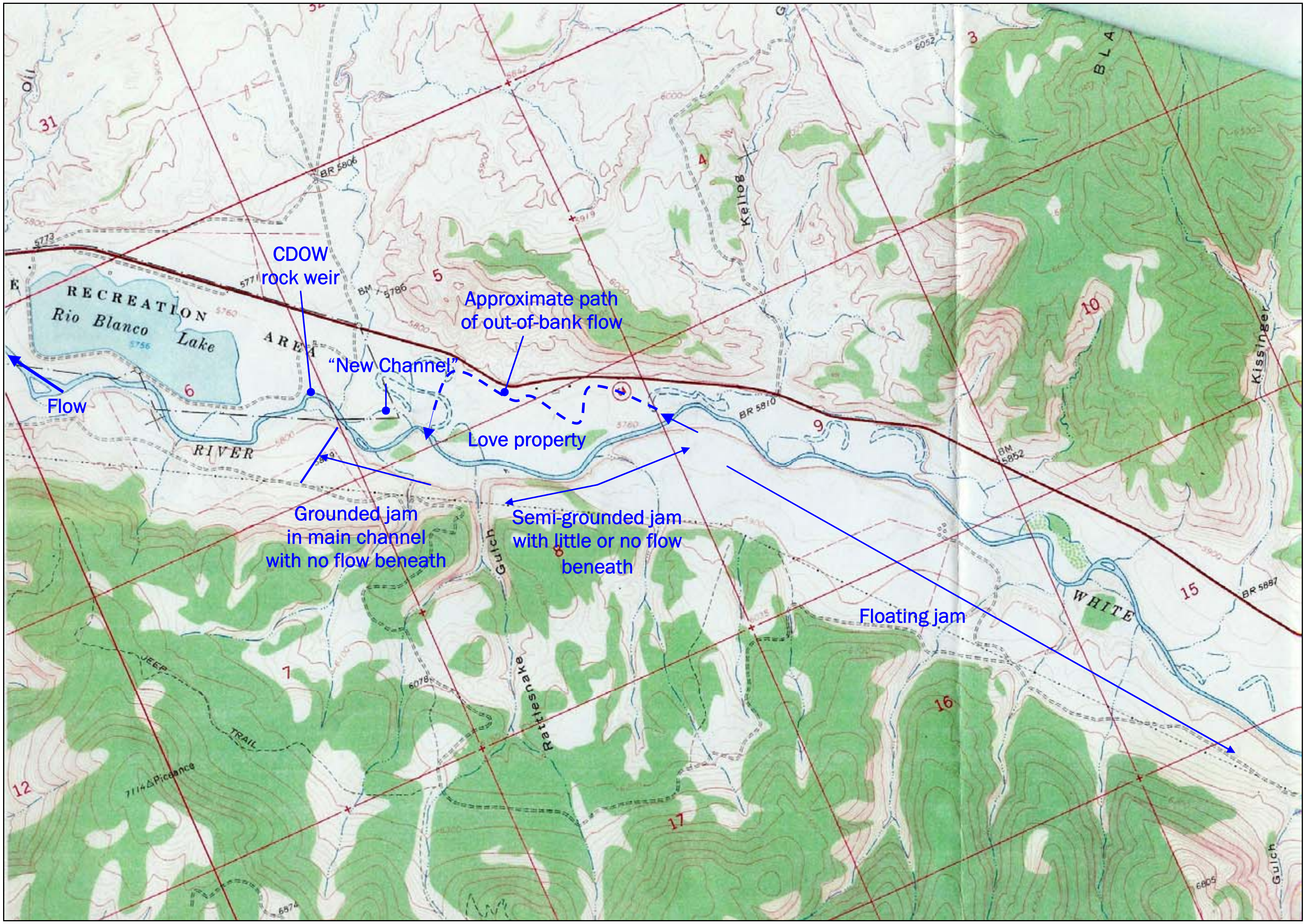

Figure 9. Ice jam problem area on White River.

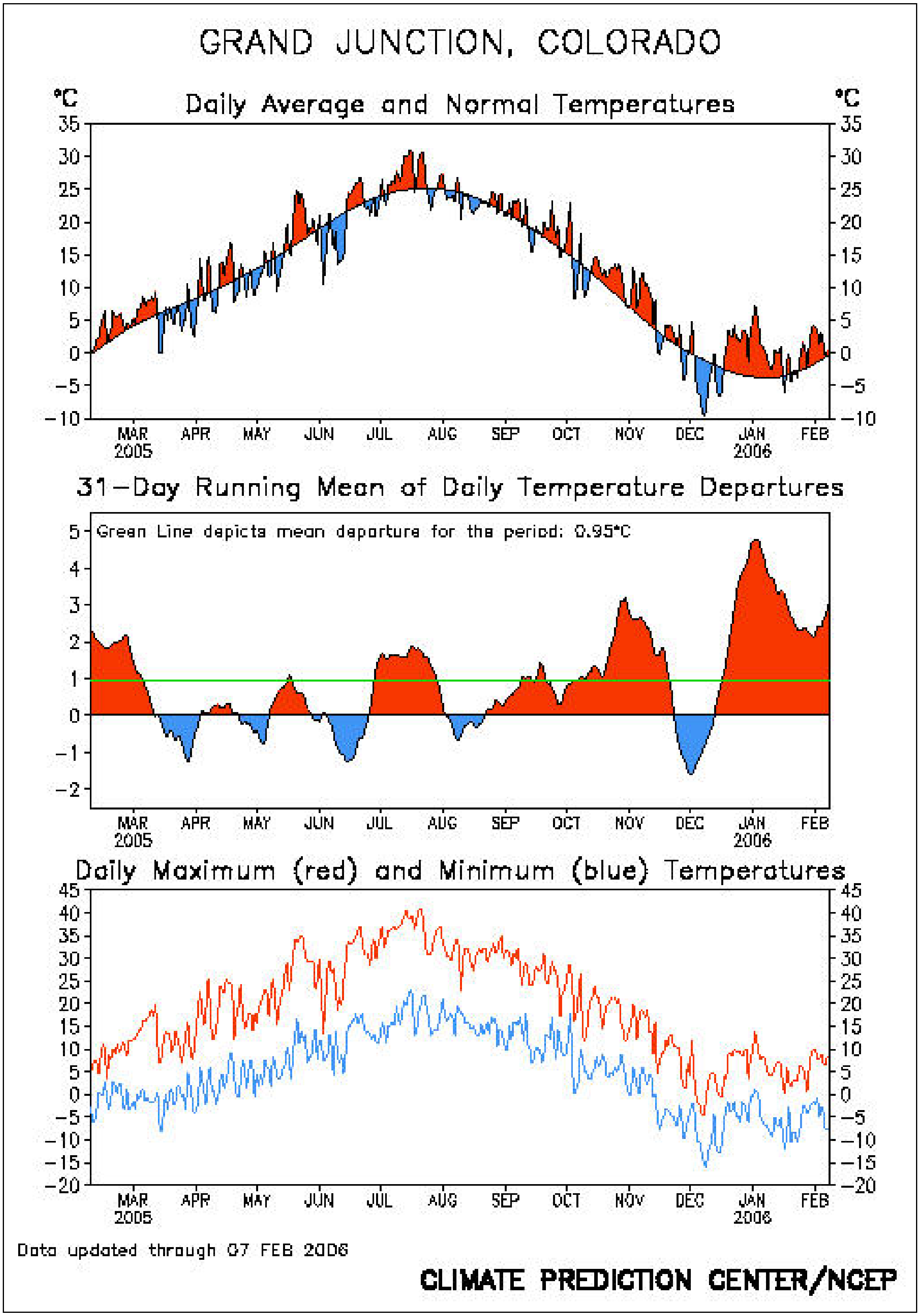

Figure 10. Winter 2005–2006 air temperatures for Grand Junction, Colorado, compared to long-term averages.

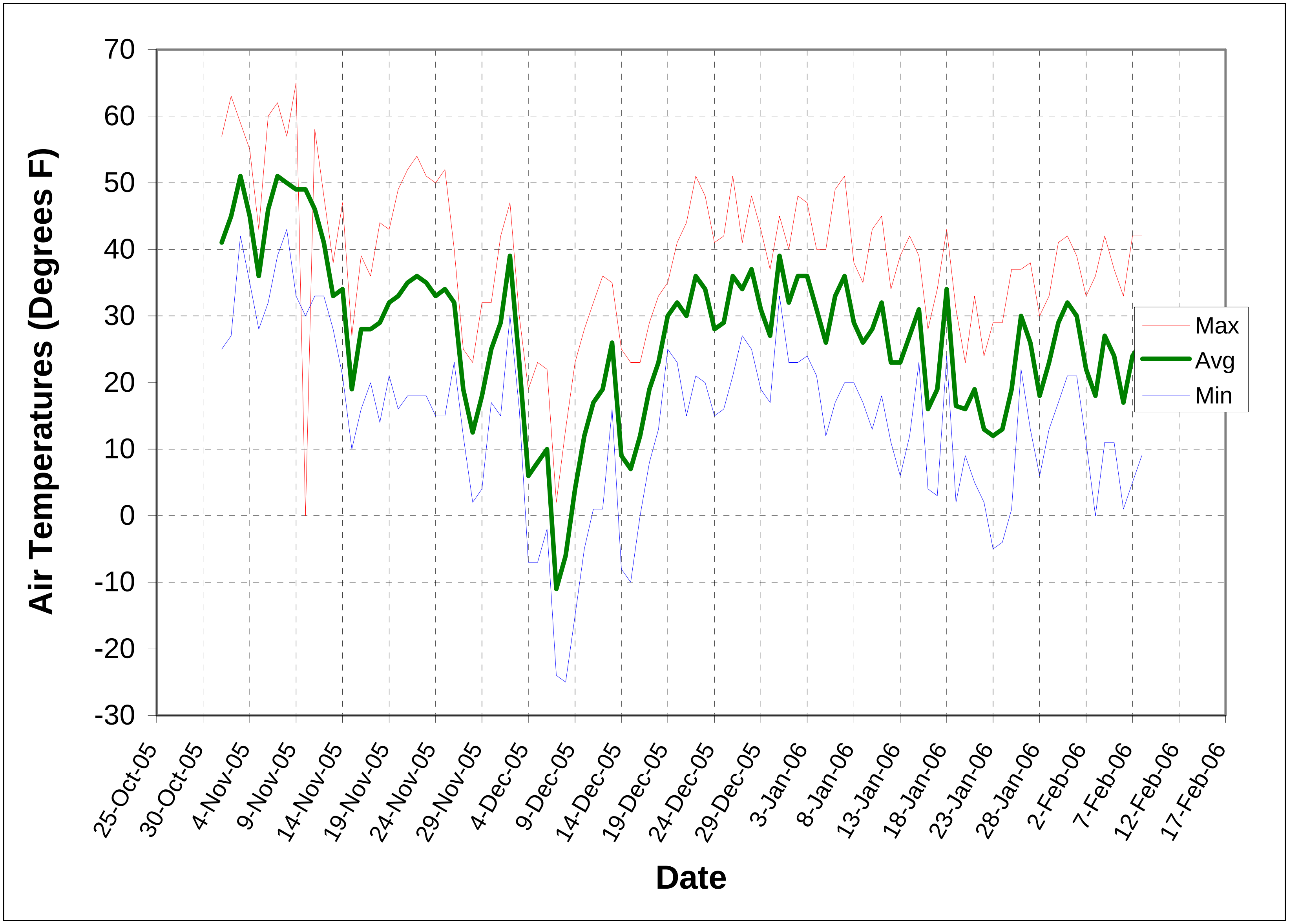

Figure 11. Air temperatures at Meeker, Colorado, airport, showing early December cold spell during which ice jam formed.

Field Observations

On 17 January, CRREL, USACE, and CDOW representatives met at the project site with Sam Love to discuss the situation and inspect the breached CDOW weir and upstream areas inundated by the ice jam. Love said that in his 10 years on the property, he had never seen ice jams or ice-related out-of-bank flooding. The frazil ice, he said, used to drift through this reach and sometimes jam in the flatter stretch of river just downstream of the Road 5 Bridge. He also remarked that, with the exception of the early-December cold snap, the 2005–2006 winter had not been abnormally cold. Attempts to access the river near the downstream end of the jam were hindered because the flooded and refrozen ice surface would not support vehicles.

On the afternoon of 17 January, CRREL contracted Coulter Aviation to photograph the river from Meeker downstream past the jam. Except for a few minor sections of ice cover, the White River was open from above Meeker to the head of the ice jam. Total ice jam length was about 3.5 miles. Although air temperatures were in the 20s, the previous night had been cold and the river was carrying frazil floes at a surface concentration of about 10 percent (Fig. 12).

On 18 January, Sam Love and CRREL accessed the jam in the main channel from the west (Waypoint 15, Fig. 13), finding a grounded, dry frazil accumulation about 2.5 ft thick, resting on a silt layer. This silt had apparently deposited under the ice jam, as the river in this area is known to be gravel and cobble-bedded. Looking to the north, overland flow could be seen spilling into the new channel from the fields on the north side of the river.

On the afternoon of the 18th and the morning of the 19th, CRREL accessed the frozen jam on foot to make a series of ice thickness measurements (shown in Figure 13). Ice conditions are described from downstream to upstream. From the CDOW weir to the outlet of the new channel (Waypoint 16), the river was about half-covered by decaying frazil ice, with the full flow of the river passing beneath the ice and within banks. The entire new channel was open, with exposed silty cut banks along the outside of the bends. These eroded banks did not look entirely new, suggesting that this secondary channel captured by the ice jam flood outflow also conveys flow during open-water season high-discharge events. At the upstream end of the new channel, overland flow could be seen re-entering the river at

multiple locations along the right bank over a length of about 600 ft. A grounded jam filled the lowermost 1500 ft of the main channel (Waypoints 16 and 15) and the dry frazil ice accumulation appeared to be draped over the channel bed topography. The ice was 2–2.5 ft thick, with no signs of flow beneath. In the area abeam the Love Ranch buildings (Waypoints 19 and 20), solid frazil 2.5–3 ft thick overlay still, muddy water 6–8 ft in depth.

This semi-floating ice jam condition continued from Waypoint 19 upstream for about a mile to Waypoint 26. At many locations in this section of the main channel, water and loose muddy frazil ice were found beneath the 2- to 3-ft-thick solid frazil layer, but no appreciable water currents were observed. Although it was difficult to discern exactly, flow appeared to be escaping the main channel and into the fields of the Love Ranch for about 1000 ft, between Waypoints 23 and 26. The solid frazil layer probably represented an initial floating ice cover formed of juxtaposed frazil floes. The loose frazil was probably drawn beneath the solid cover and deposited there to thicken the jam. The continued deposition of this frazil, and possibly silt, plugged the flow paths beneath the jam, forcing the river flow out of bank and onto the Love property.

At the time of the 18–19 January observations, upstream of Waypoint 26 the ice cover was floating and within banks, with the bulk of the river flow passing beneath. In an early February visit, however, USACE observed that ice and flood conditions at the Love Ranch had worsened, and the jam and out-of-bank flow conditions similar to those witnessed at the Love property had progressed several miles upstream of its January location.

Remedial Efforts

On 10 January, USACE and CDOW allowed Love to remove a section of the weir using a large excavator (Fig. 14). This action, combined with the effect of more moderate air temperatures, caused most of the ice cover to melt out for about one mile above the weir (Fig. 7). The ice jam in the main channel adjacent to the Love Ranch remained in place, however, and continued to divert nearly all the river flow across the Love property.

On about 23 January, Love contracted a high-track D-8 Cat to attempt to excavate a 20-ft-wide channel through the grounded and semi-grounded portions of the ice jam from Waypoints 16 to 26. It was hoped that this would cause the river flow to return to the main channel, alleviating the

upstream flooding. Shortly after accessing the downstream end of the jam, the D-8 got stuck in riverbed silt deposits estimated by Love to be 3 to 4 ft thick. A larger D-9 cat was called in to pull out the D-8. The presence of these thick silt deposits was somewhat of a surprise, as the predominant bed material in this section of river is in the gravel-to-cobble size range. The best guess at this point is that the silt deposition is related to the ice jam. After nearly losing the D-8, the excavation option was called off.

Blasting a channel through the jam using explosives was also considered, but was ruled out because of cost. It is also uncertain whether blasting would be successful, because little to no current exists in the main channel to carry the ice fragments downstream.

Figure 12. Drifting frazil ice upstream of ice jam on 17 January 2006. Flow direction is right to left.

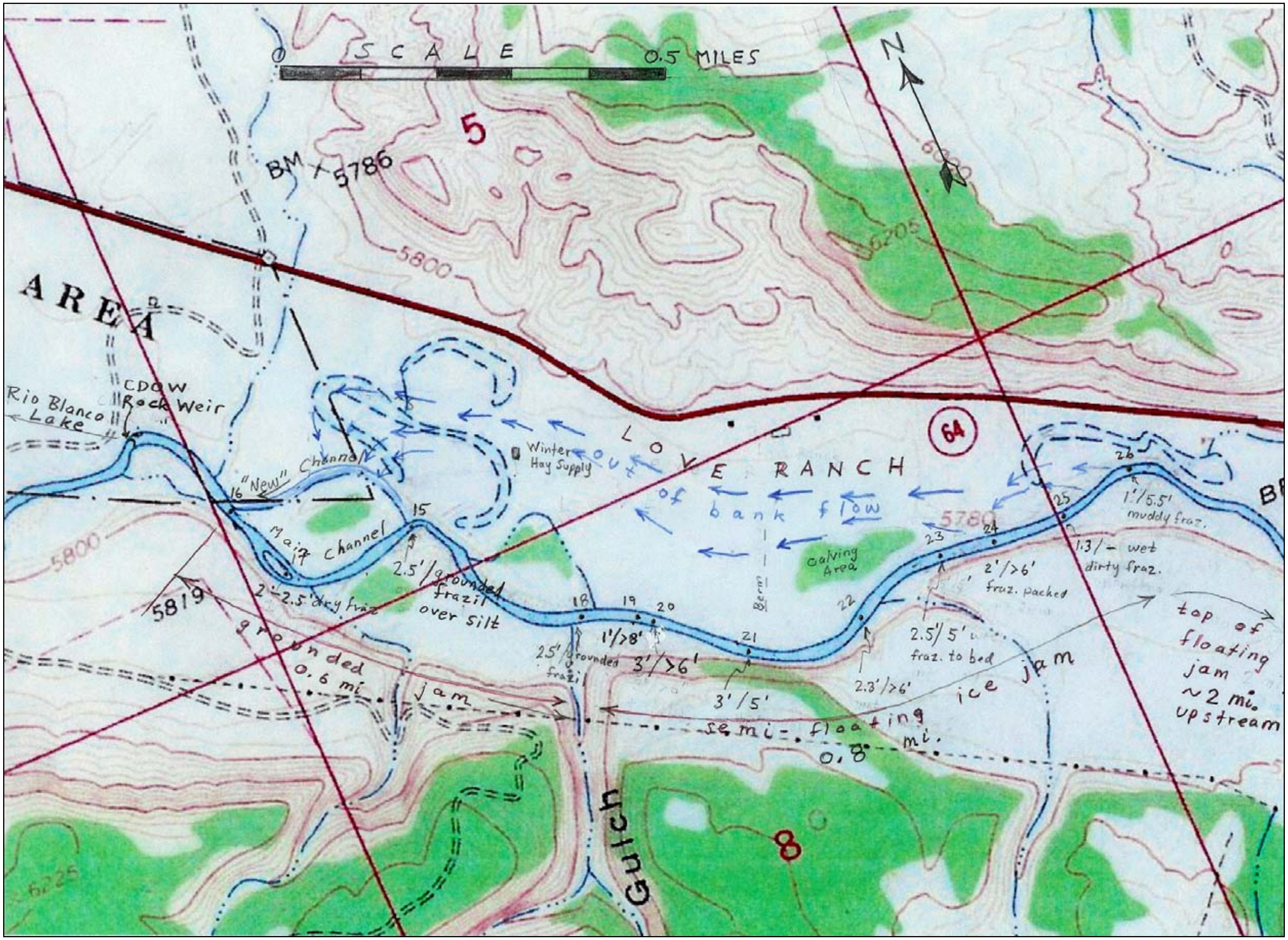

Figure 13. Ice jam thickness measurements.

Figure 14. Breached CDOW rock weir, 17 January 2006.

3 Discussion

Hydraulic Aspects of the CDOW Rock Weir

Figure 4 shows before-and-after weir cross sections. The previous structure was about 2 ft high at its lowest point, with a U-shaped cross section roughly parallel to the existing river bed. At low flows, the depth upstream of the weir was about 4 ft, the water surface width was about 65 ft, and the cross-sectional flow area at the weir crest was about 80 ft^2. The new structure increased the design low-flow open-water depth to about 6 ft, with flow passing through a 23-ft-wide by 2-ft-deep cutout spillway section. Based on Figure 3, the flow area through the new spillway section is about 20 ft^2. With the spillway crest ice-clogged as shown in Figure 2, the upstream water surface elevation is about level with the new weir crest, giving a water depth of about 6 ft. Assuming an average bed slope of 0.00395[1] upstream of the weir, this 3-ft increase in water surface elevation would extend the low flow backwater distance from about 500 ft to 1260 ft.

Tendency for Ice Retention at the Weir Based on Existing Theory

The complex processes on ice passage, retention, and jamming are the subject of much research and sophisticated numerical modeling, well beyond the scope of the current discussion. In the simplest sense, whether or not an in-stream structure or weir will pass or retain ice depends on at least two factors. The first is the gap width and the second is the average surface velocity in the pool upstream, which is governed in part by depth.

Theory developed through experiments by Calkins and Ashton (1975) predicts that, for surface ice concentrations greater than about 30%, ice floes will arch across a gap if average floe diameter is more than one quarter of the gap width. Based on discussions with locals and photos of the river (e.g., Fig. 12), floes moving through this section of the White River can be at least 15 ft in diameter and surface ice concentrations can exceed 30%. According to ice arching theory, gap width should therefore be at least 60 ft.

[1] Based on analysis of 1:24,000 USGS quad mapping (Fig. 9)

An in-stream structure or weir raises the water level, increasing the cross-sectional flow area and reducing the water velocity in the pool upstream. From observation and theory, where water velocity decreases to below about 1 ft/s, drifting frazil ice is likely to stall and form an ice cover across the pool. More detail on the relationship between water velocity and ice cover formation is provided in Perham (1983) and Tuthill (2008). This ice cover, once formed, will block the passage of ice floes from upstream, faster moving sections of river. This is most likely what initiated the ice jam at the Rio Blanco weir in December 2005.

Based on the CDOW weir cross sections (Fig. 5), water velocities on the pool upstream of the weir were calculated assuming an average winter baseflow of 350 cfs. Three cases were considered: 1) a no-weir case, 2) a pre-2005 weir case, and 3) a 2005 and after weir case.

1) For the no-weir case, assuming a top width of 70 ft and an average depth of 1.5 ft, the average velocity would be 3.3 ft/s. Under these conditions, one would expect the frazil floes to pass the pool and the 70-ft weir opening without problems as they do in the upstream river channel between the town of Meeker and the Rio Blanco weir.

2) For the pre-2005 weir case, with a top width of about 60 ft and an average upstream depth of about 2.5 ft, the approach velocity would be 2.3 ft/s, which would still favor ice passage rather than retention.

3) For the 2005 weir, with an upstream top width of about 130 ft and an average upstream water depth of 4 ft, the upstream approach velocity would be about 0.7 ft/s. This is slow enough for the frazil ice floes to stall in the upstream pool independent of the 30-ft gap width at the weir (which would probably cause arching).

Based on these observations, to ensure against ice jam formation, it would probably be necessary to lower the pool elevation by about 2 ft (close to pre-2005 conditions) and maintain a gap width of at least 60 ft.

4 Conclusions

Based on field observations and simple ice hydraulic theory, the 2005 raising of the CDOW weir most likely initiated the freezeup ice jam that formed on the White River in Colorado in December 2005.

The 2005 weir design needs to be modified to pass frazil ice during the winter season. Possibilities include increasing the spillway gap width to at least 60 ft and also providing some type of crest control to lower the winter pool level, and then re-raising it to fill the diversion channel.

In order to evaluate these and other long-term mitigation alternatives, upstream channel geometry needs to be surveyed. The survey could be as basic as a series of water surface elevations and thalweg depths taken at 100- to 200-ft increments, along with top-width measurements or estimates. The survey information provides inputs to simple ice-hydraulic models such as HEC-RAS, used to evaluate various solution alternatives. These steps often are omitted because of their assumed high cost and time requirements. The cost of skipping the survey and hydraulic calculations can be considerably higher, though, if the structure fails to perform as anticipated.

Finally, relatively little is known about the effect of in-stream structures on river ice regime, and almost no design guidance is available for designers and regulators. This event provided valuable insight in the development of basic design guidelines for riverine structures on ice-affected rivers, a research effort under way at CRREL.

5 References

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Perham, R.E. (1983) Sheet Ice Retention Structures. US Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, CRREL Report 83-30.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

In-stream structures constructed of natural materials are increasingly popular on US rivers. Examples include rock weirs that provide an aesthetic means of pooling and diverting flow for irrigation and lake filling. Though considerable progress has been made in the design and construction of these soft engineering structures, most applications to date have been on rivers that are unaffected by ice. Recent experience shows that the presence of ice can have unexpected and possibly negative results. This report presents a case study of a rock diversion weir that caused a freezeup ice jam, channel shifting, and upstream flooding. The event is described and its causes analyzed. Preliminary guidance is offered on designing against similar ice problems when locating these new types of structures on rivers with ice.

15. SUBJECT TERMS

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